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Massive Stars Across Redshifts in the Era of JWST and Large-Scale Surveys

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# Deep Atmosphere Models of Very Massive Stars

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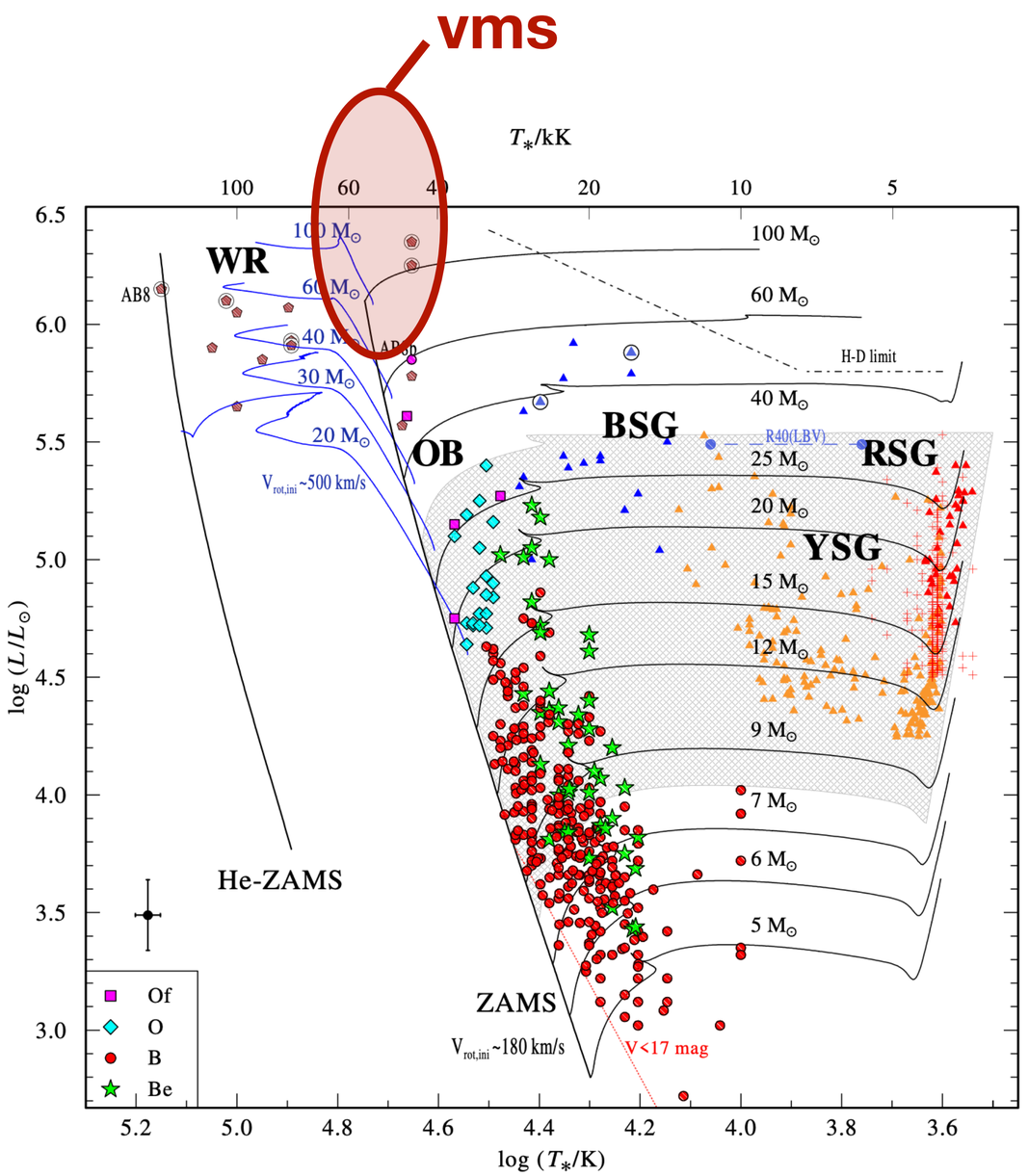
# very massive stars

- initial mass > 100 $M_\odot$
- few, but very luminous
- strong wind feedback
- unique main-sequence evolution (O→WNh)




Ramachandran et al. (2019)

# our models

| | evolution **GENEC** | atmospheres **PoWR** |
|---|---|---|
| input | Mass, Metallicity, Rotation<br><br>(+ evolution settings) | Stellar parameters (M, L, R, abundances)<br>Wind parameters ($\dot{M}$, $v_\infty$)<br><br>(+ atmosphere settings) |
| physics | hydrostatic equilibrium<br>energy transport w/ tabulated opacities<br>angular momentum transport<br>nuclear burning, mass loss<br>grey atmosphere | hydrostatic equilibrium (in inner part)<br>detailed radiative transfer<br>expanding atmosphere, non-LTE |
| output | full interior structure across the evolution<br><br>evolution of stellar parameters (L, Teff, M, …) | static atmosphere structure<br><br>emergent spectrum |

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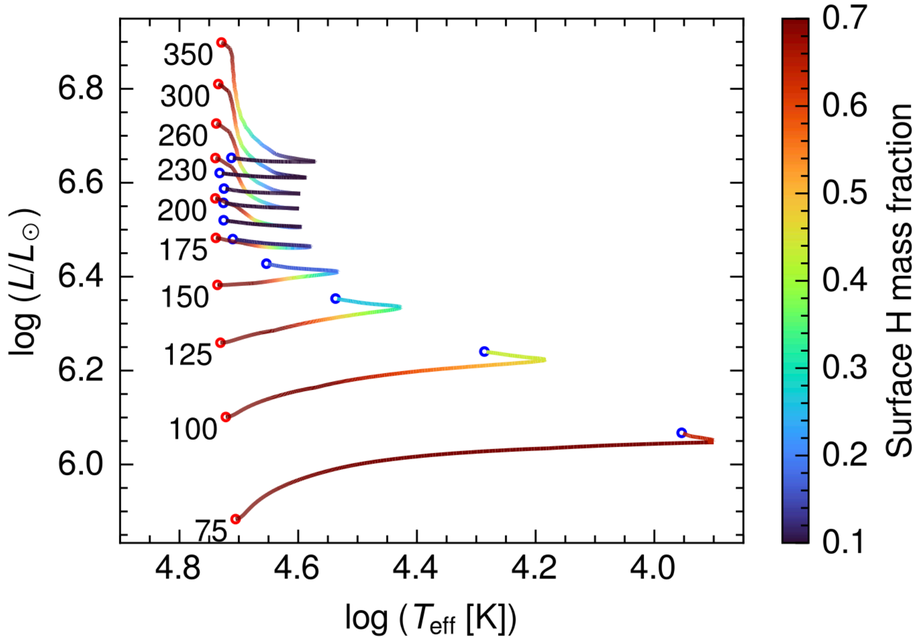
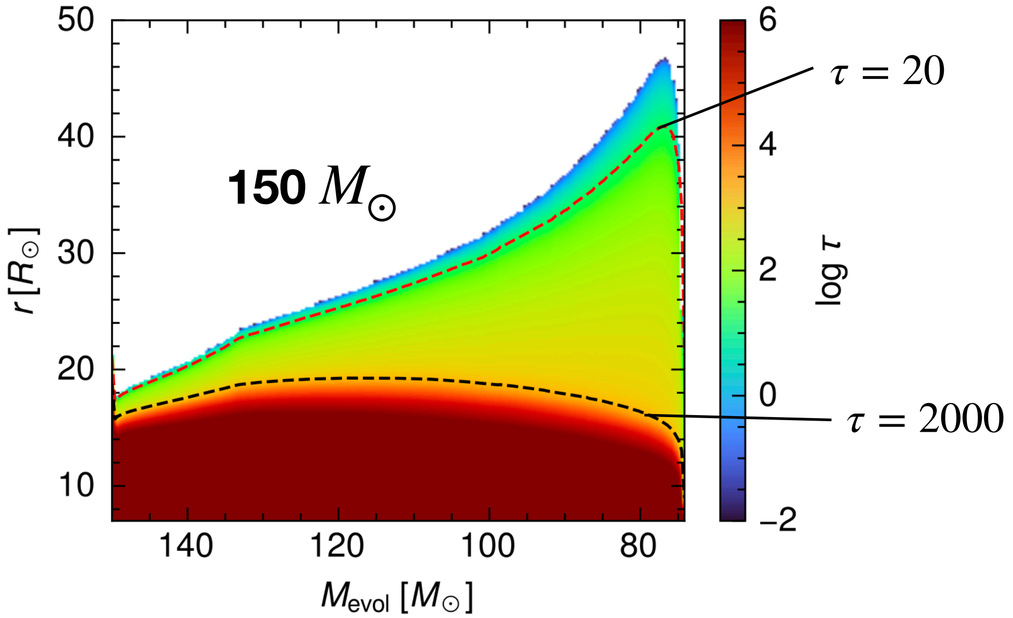
**different physics, different purpose**

# evolution models predict inflation




non-rotating models in the HRD
(main sequence only)




optical depth profile across evolution

evolution to **cooler** Teff ← **subsurface** opacity effect (iron bump)

Figs. from Josiek et al. (2025)

missing detailed radiative transfer, winds and non-LTE effects.

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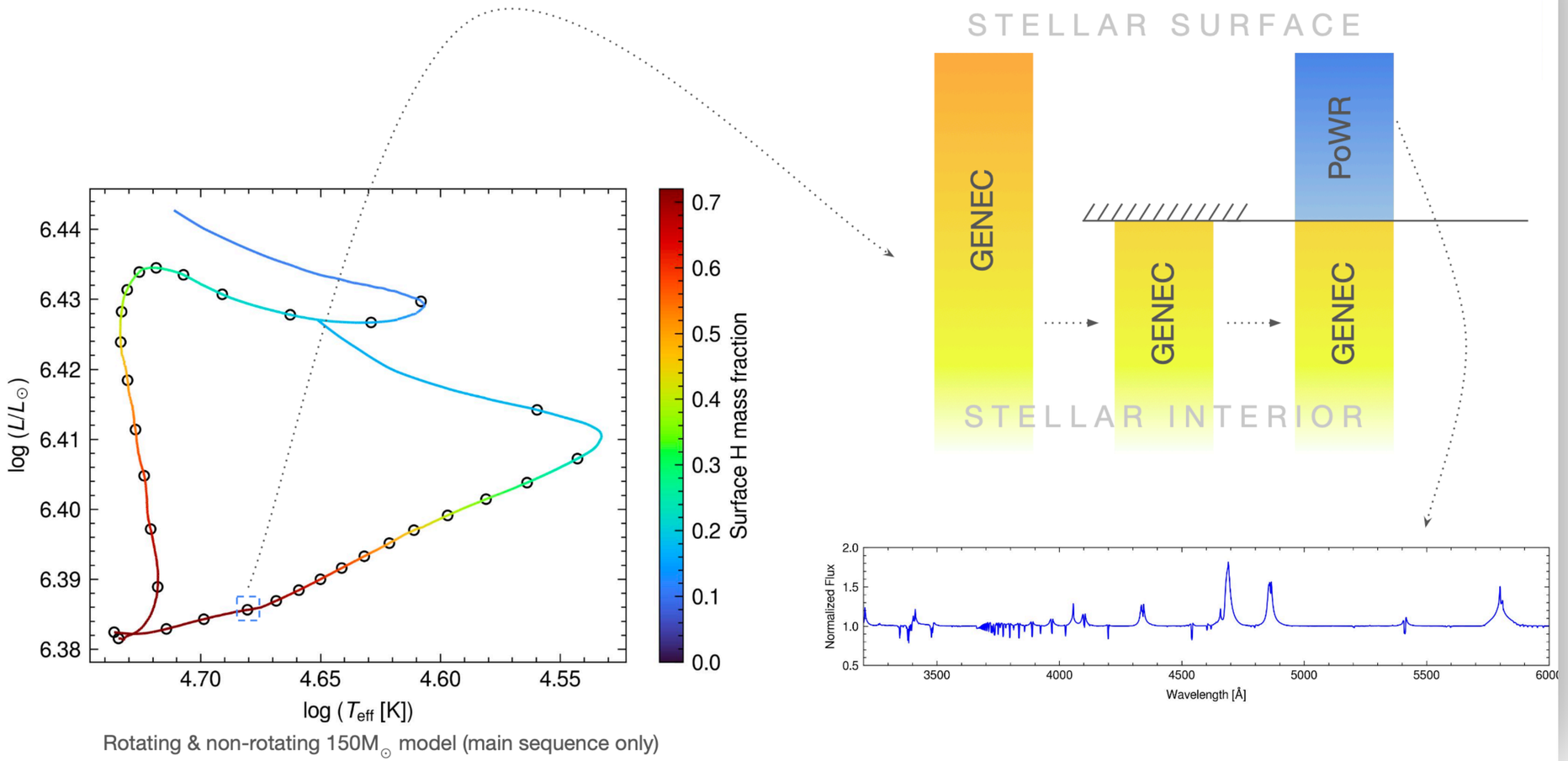
$T_{\rm eff}$ is not well-defined.

# connecting atmosphere models




Slide adapted from J.Josiek (POEMS conference, June 2024)

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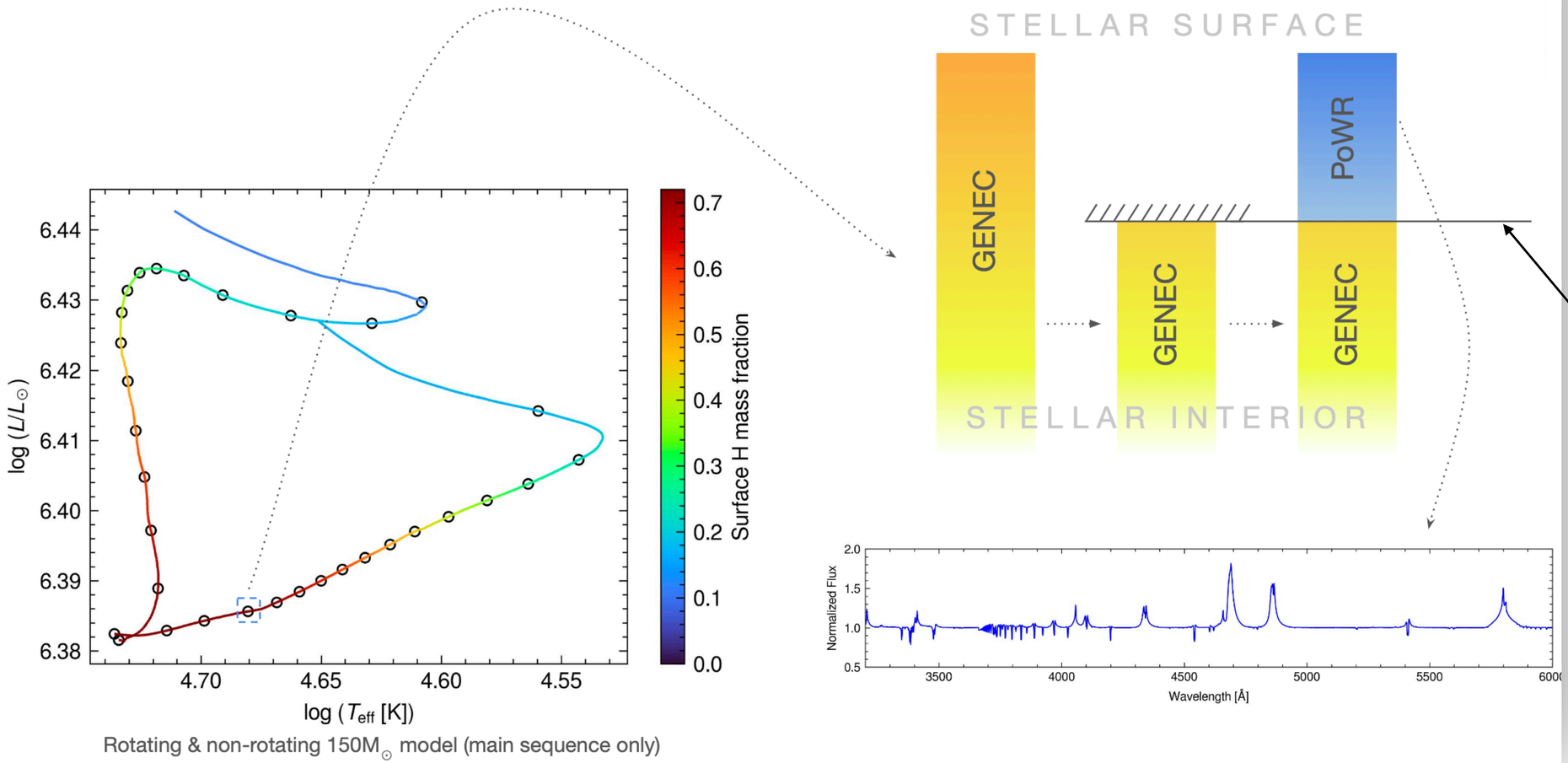


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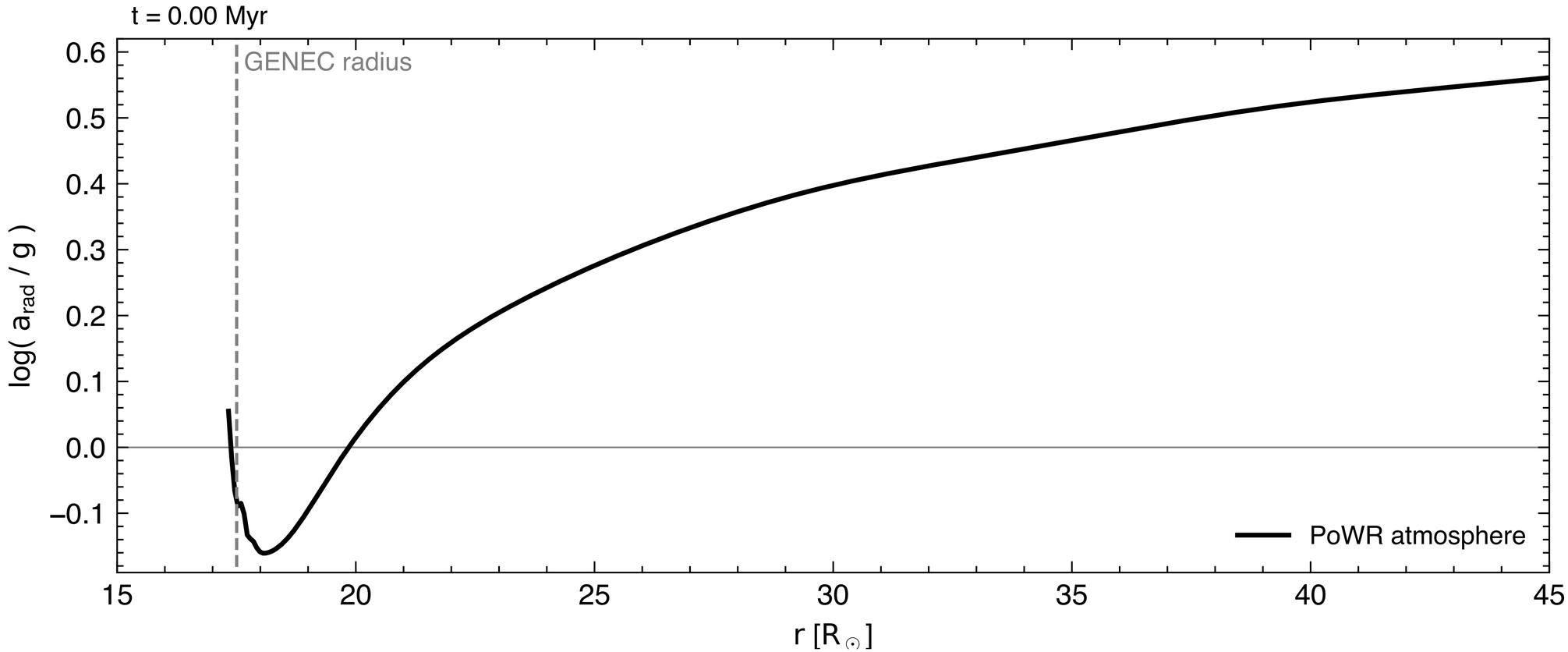
# radiative force in the wind



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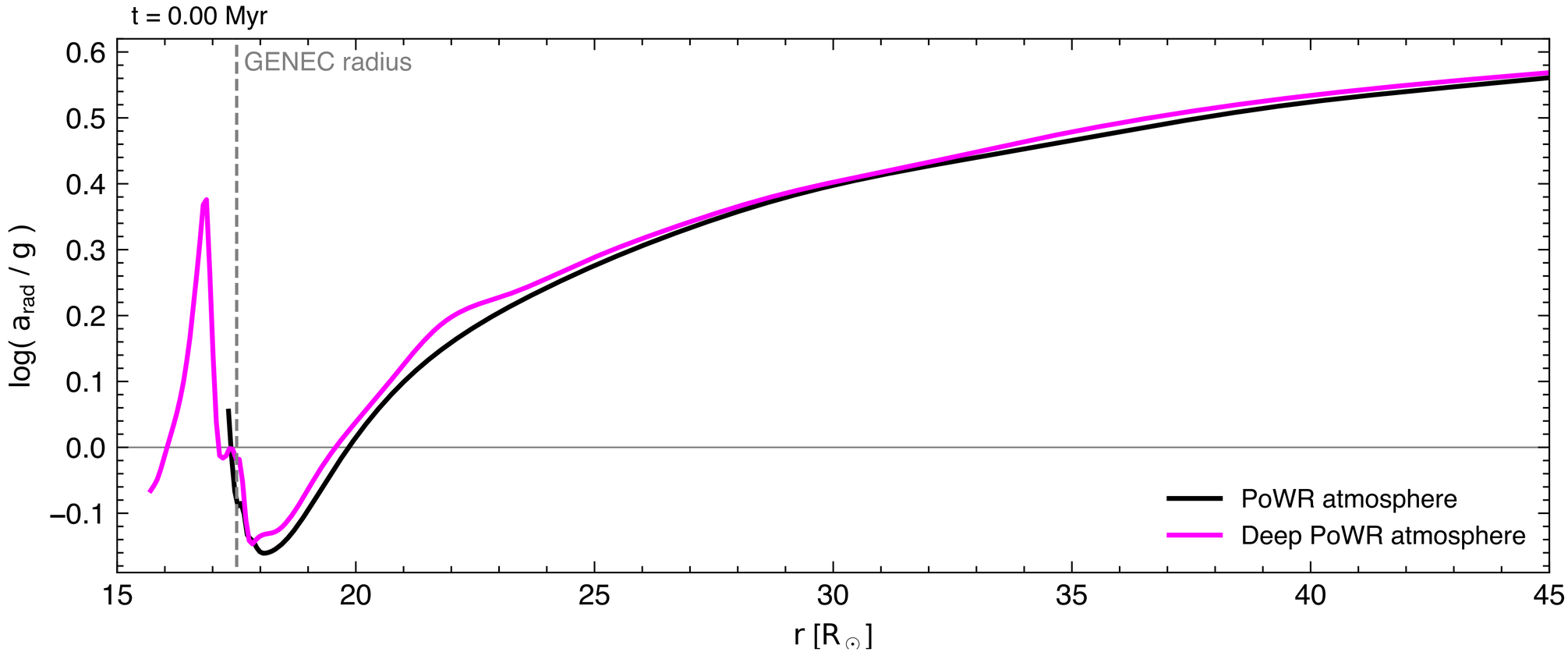


deep model attached based on density criterion ( $\rho(R) = 10^{-7}\,\mathrm{g/cm^3}$ )

→ ensures continuity with interior structure

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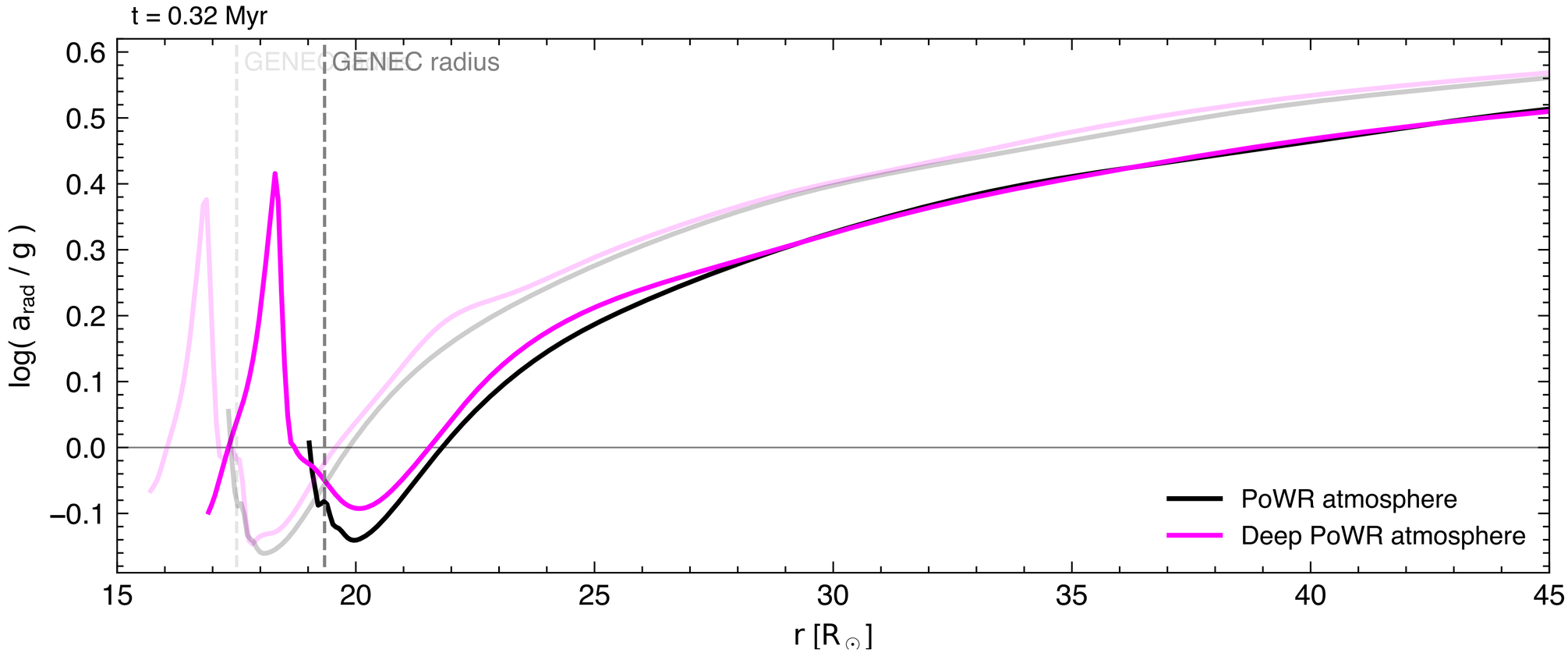

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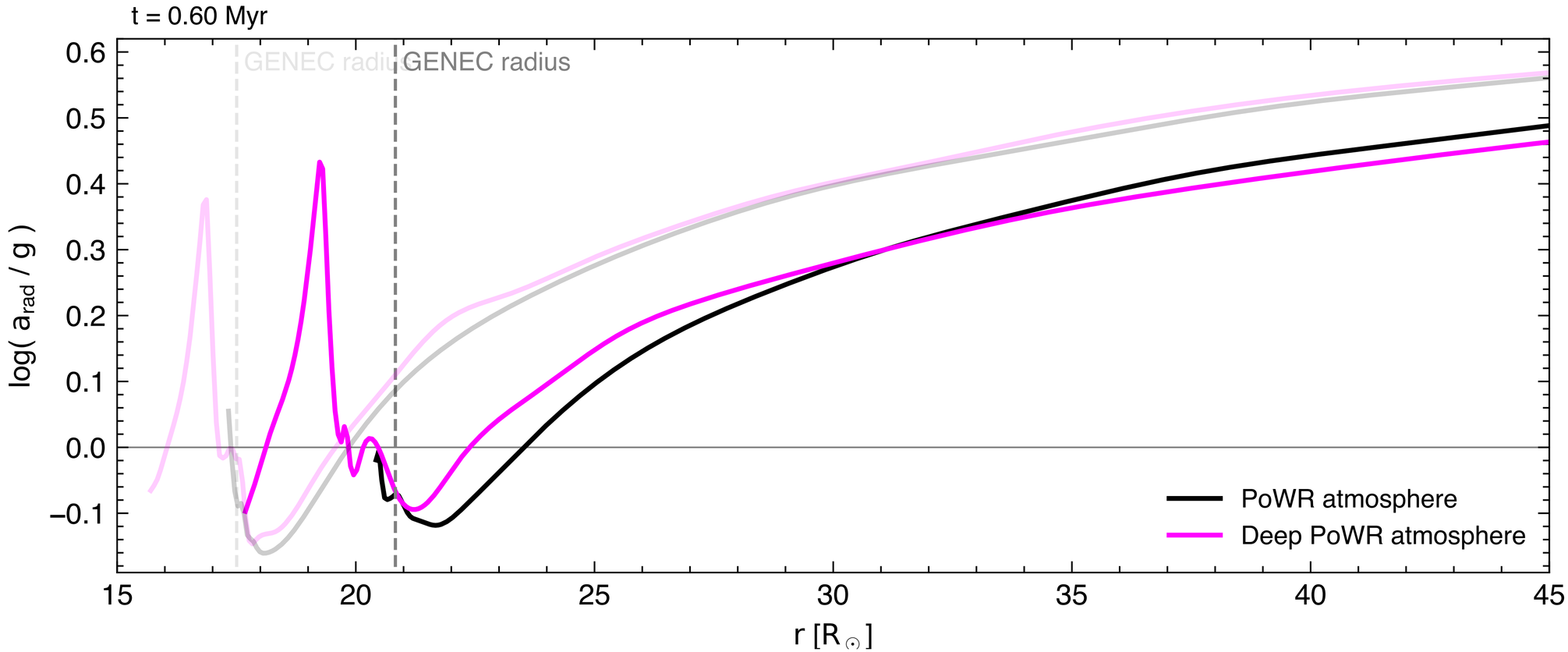

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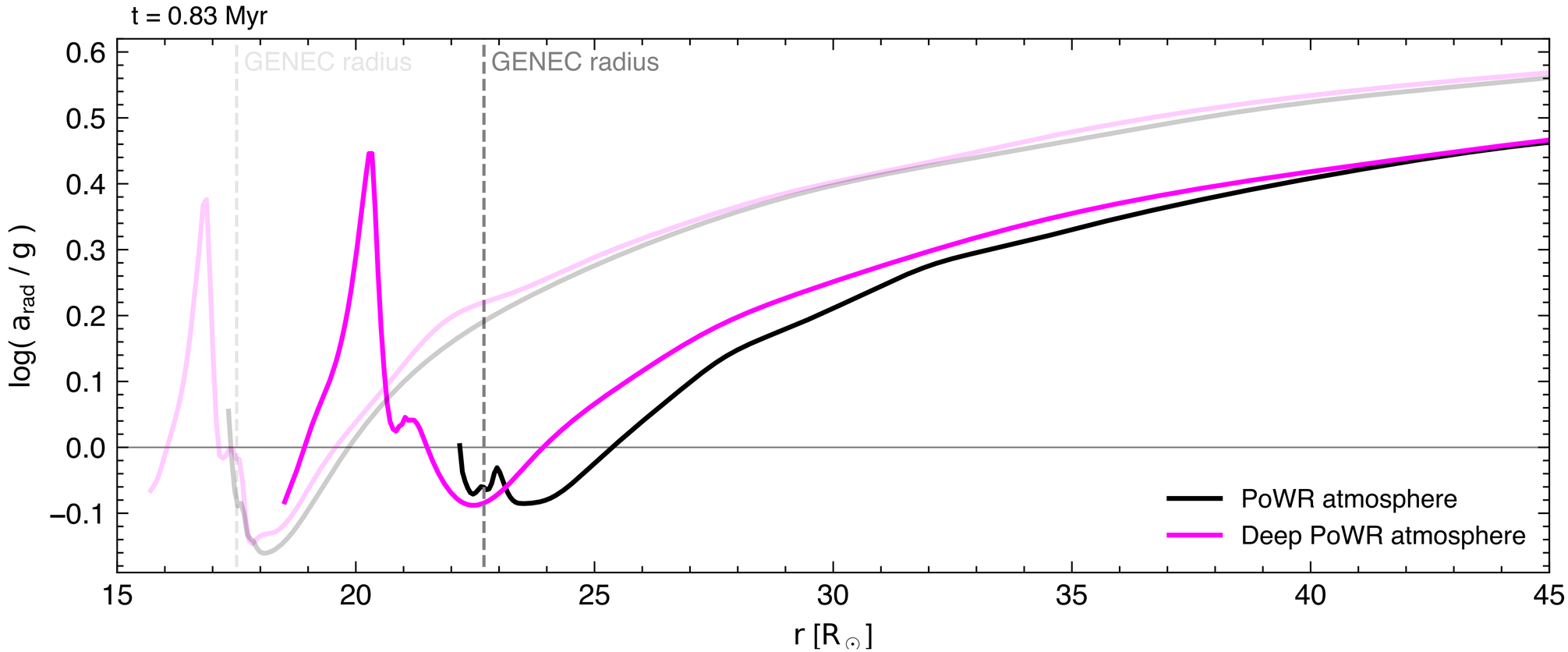

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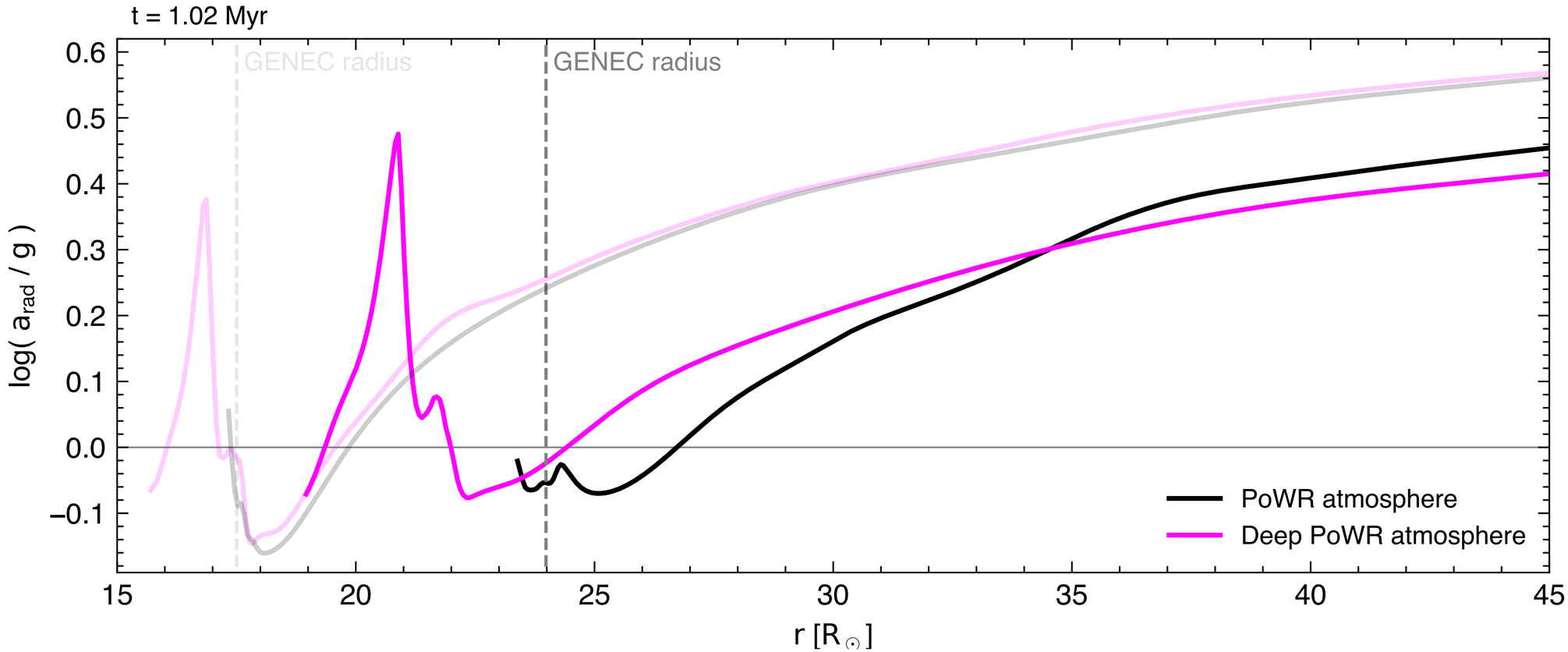

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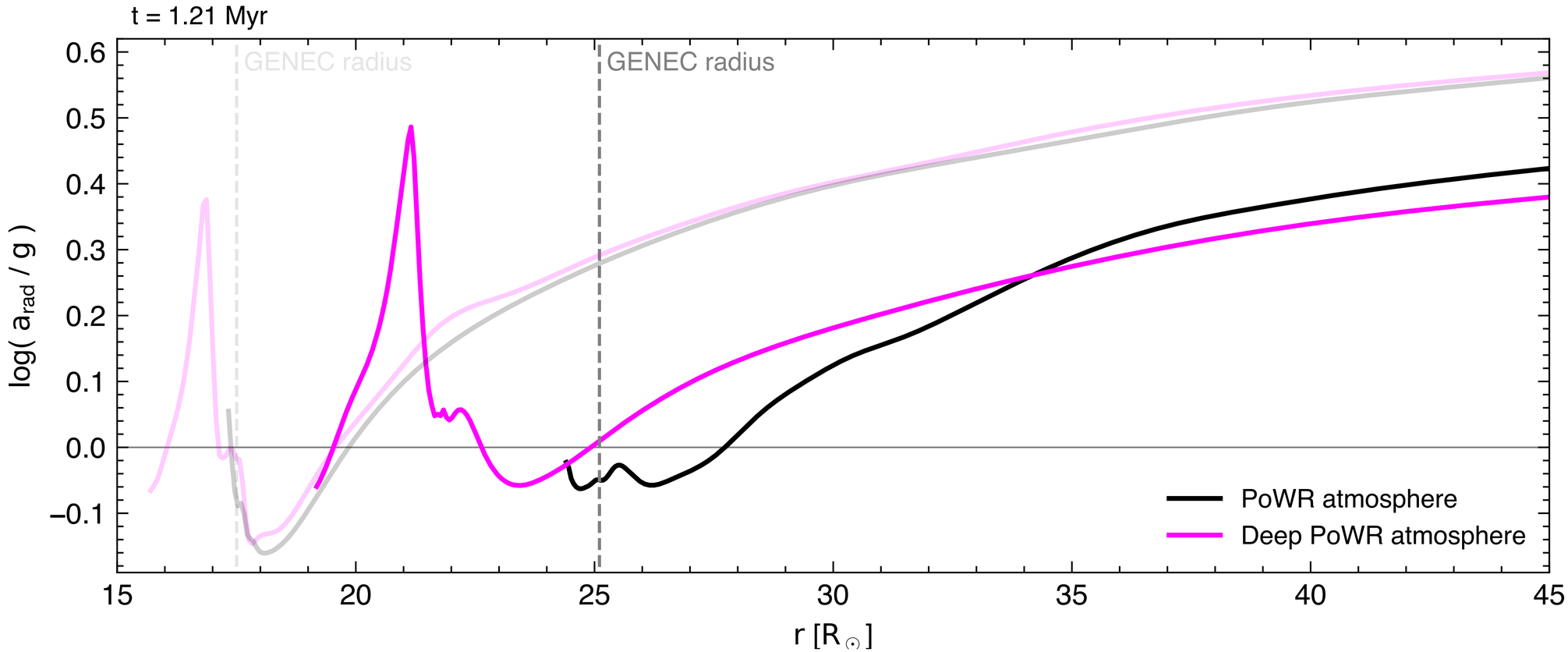

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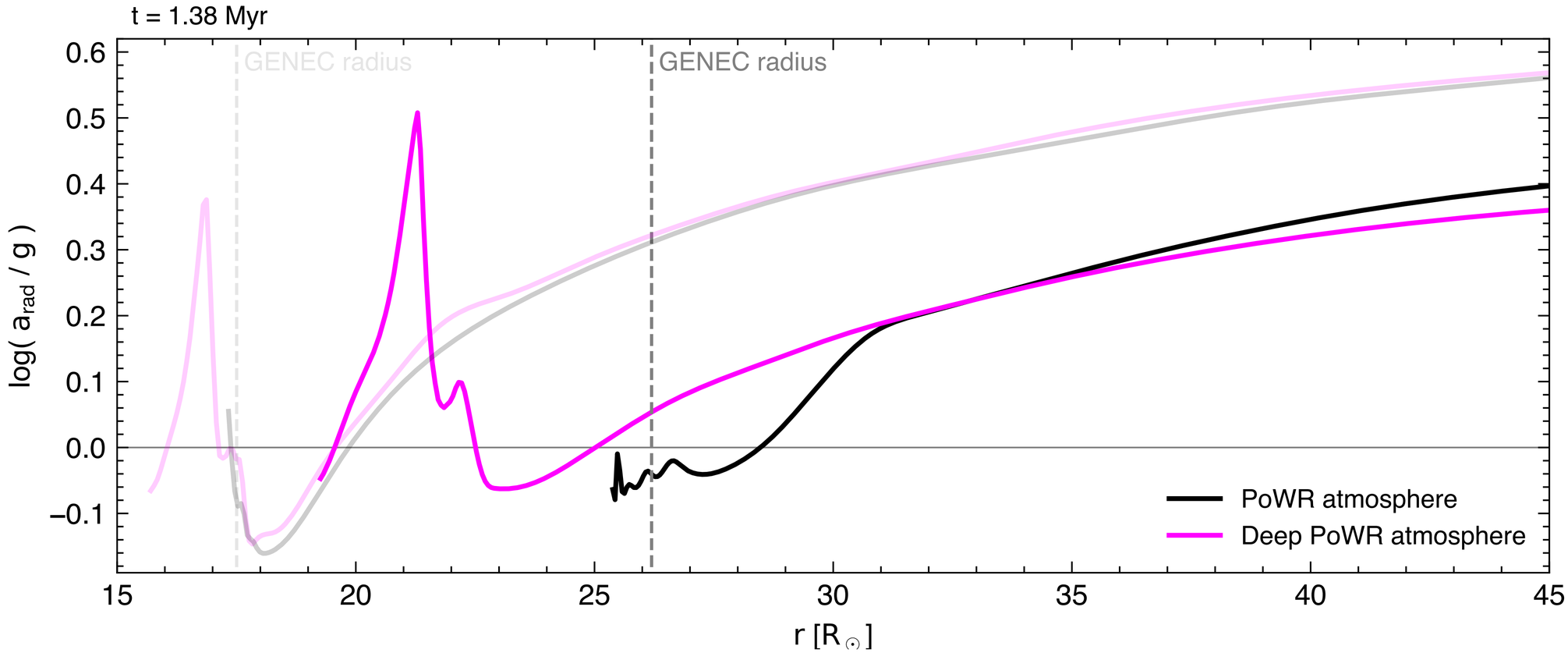

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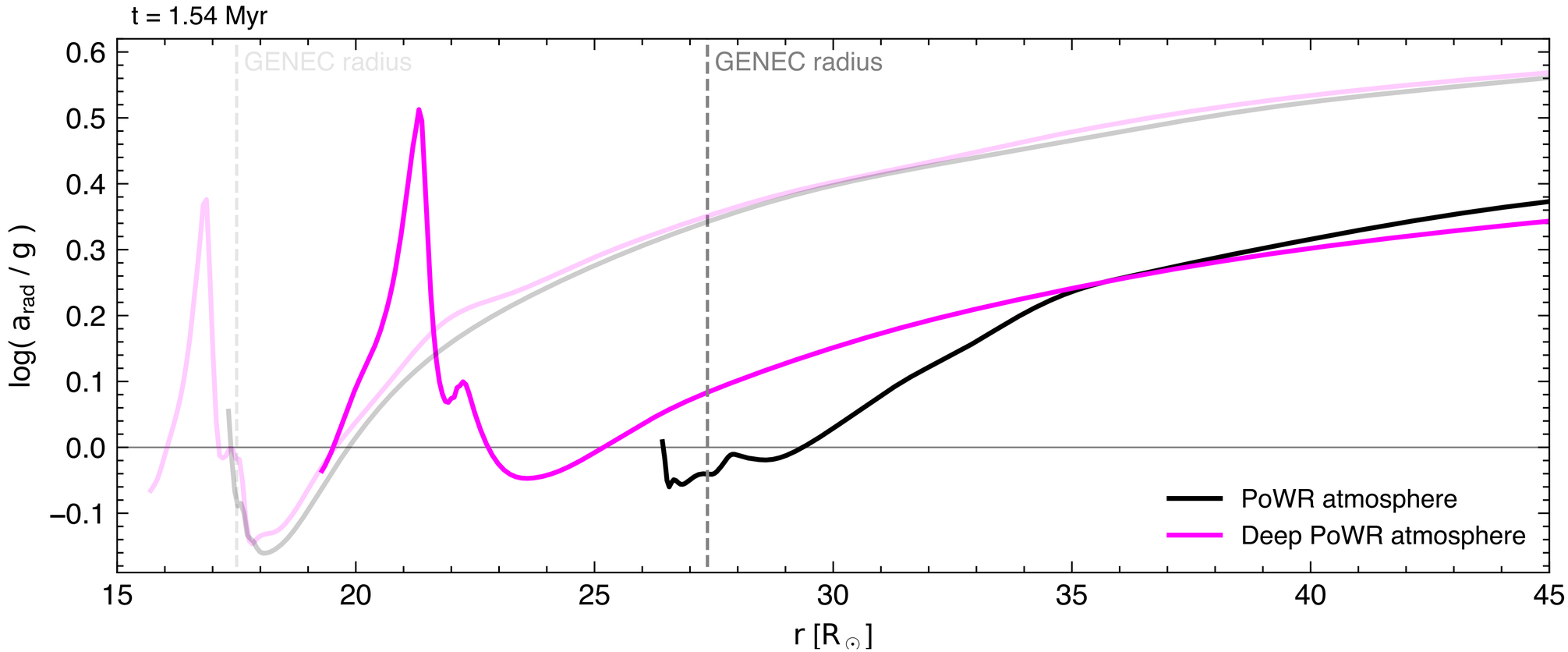

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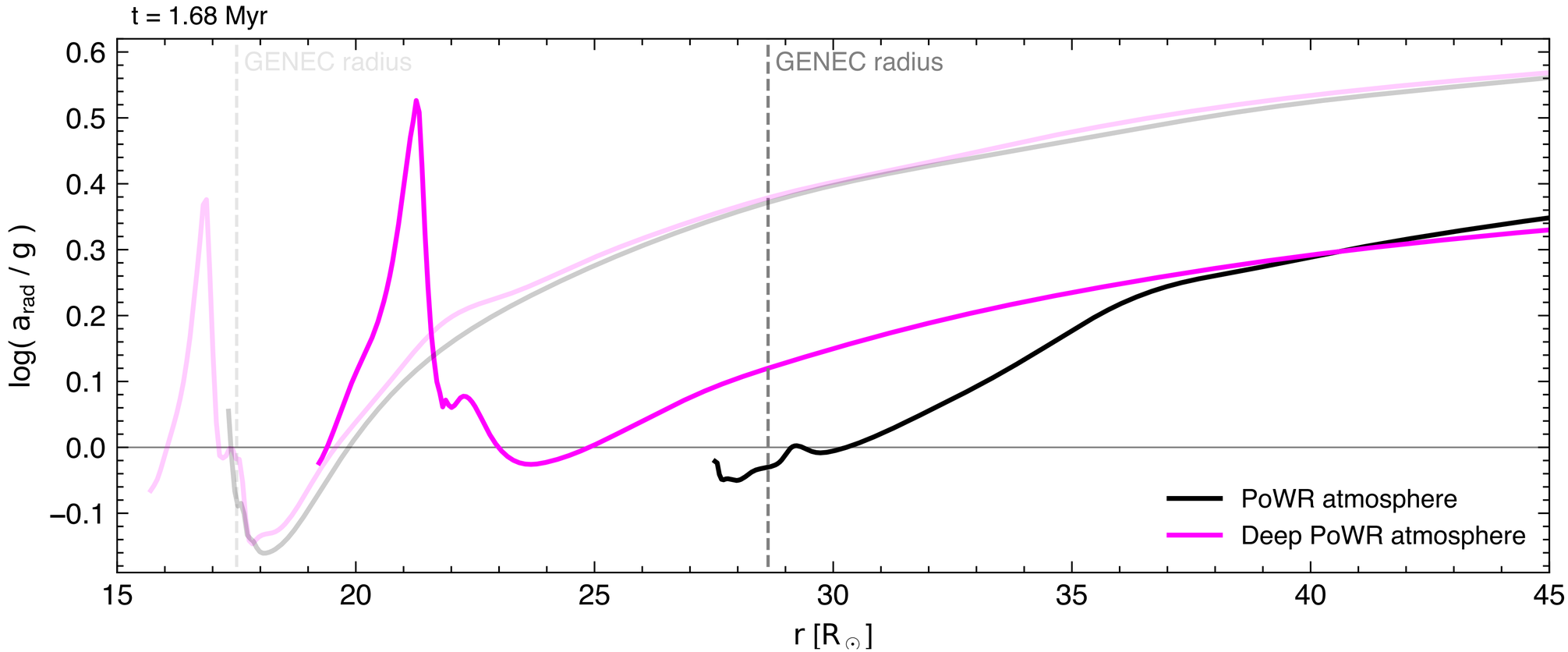

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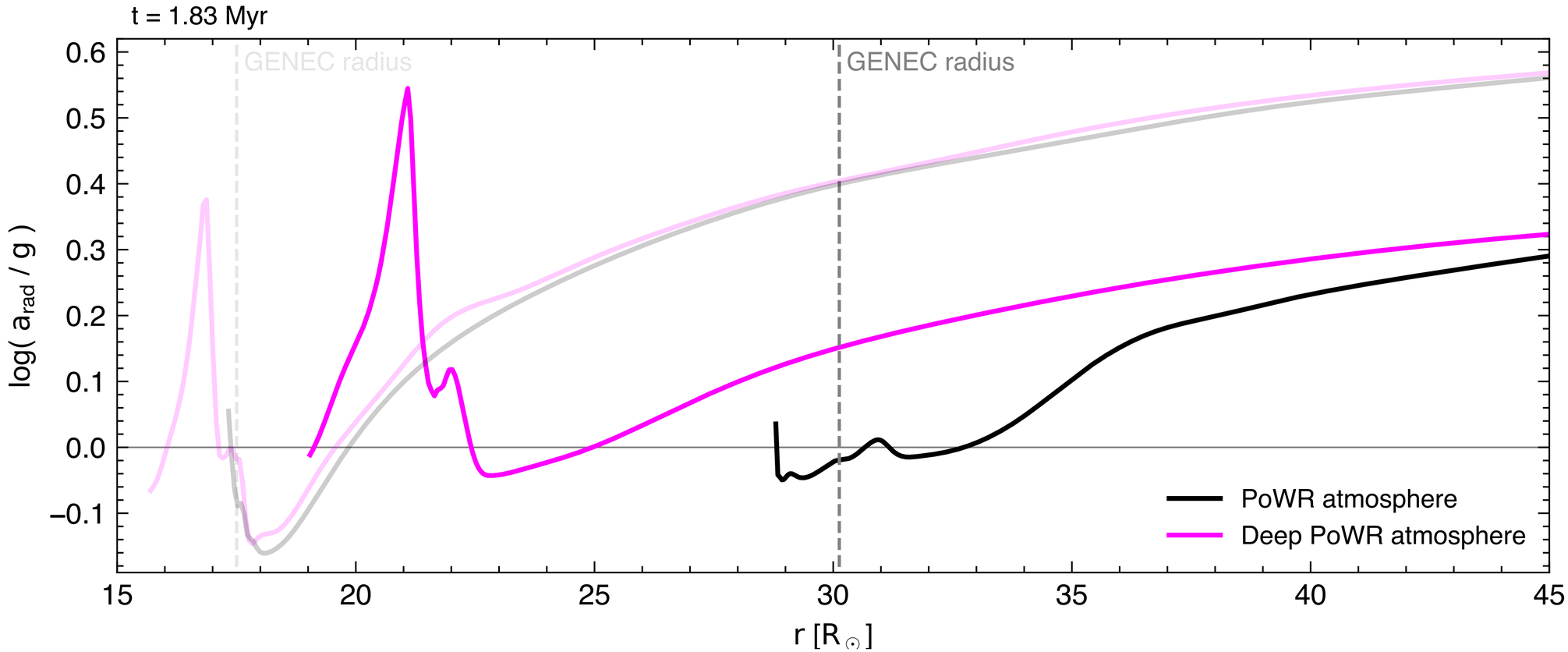

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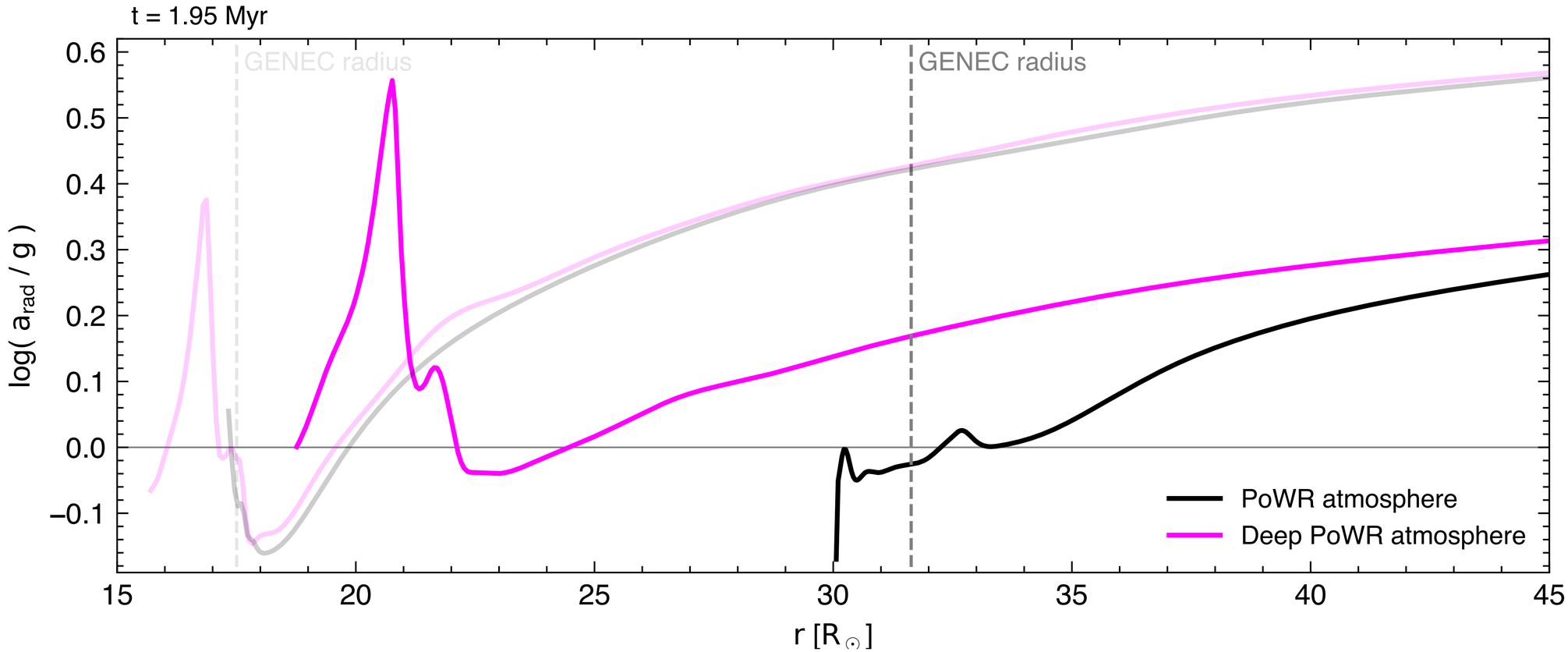

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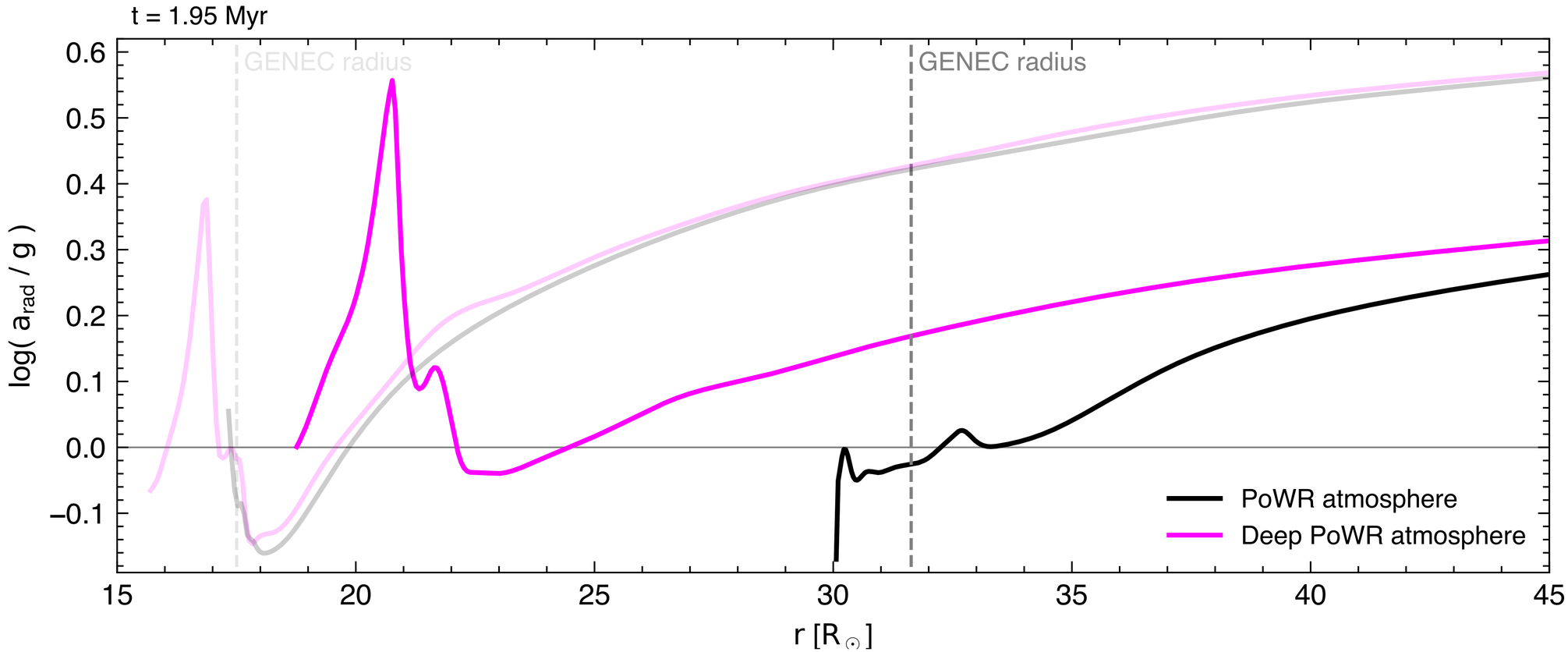
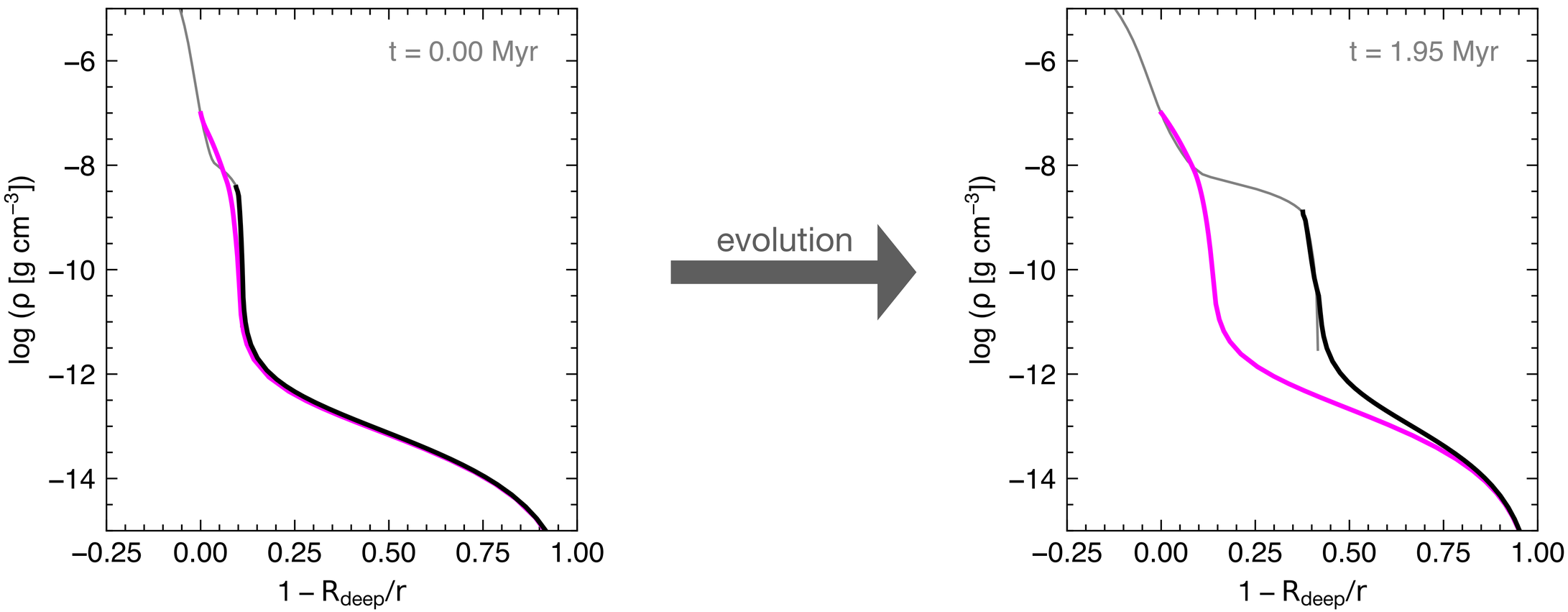



- deep atmosphere models mostly bypass inflation
- radiative force has no effect on the atmosphere structure yet (prescribed velocity field)

# density profile



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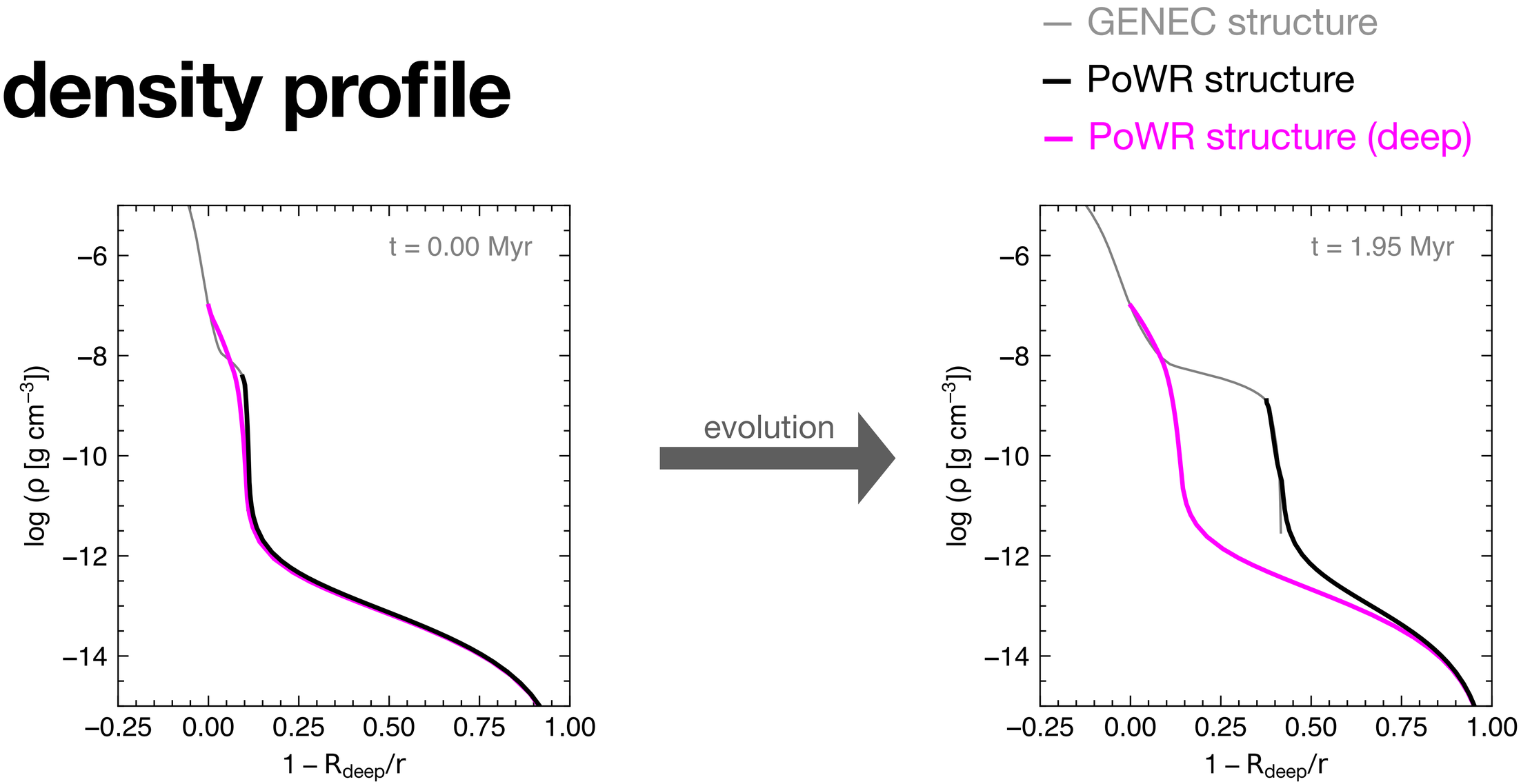
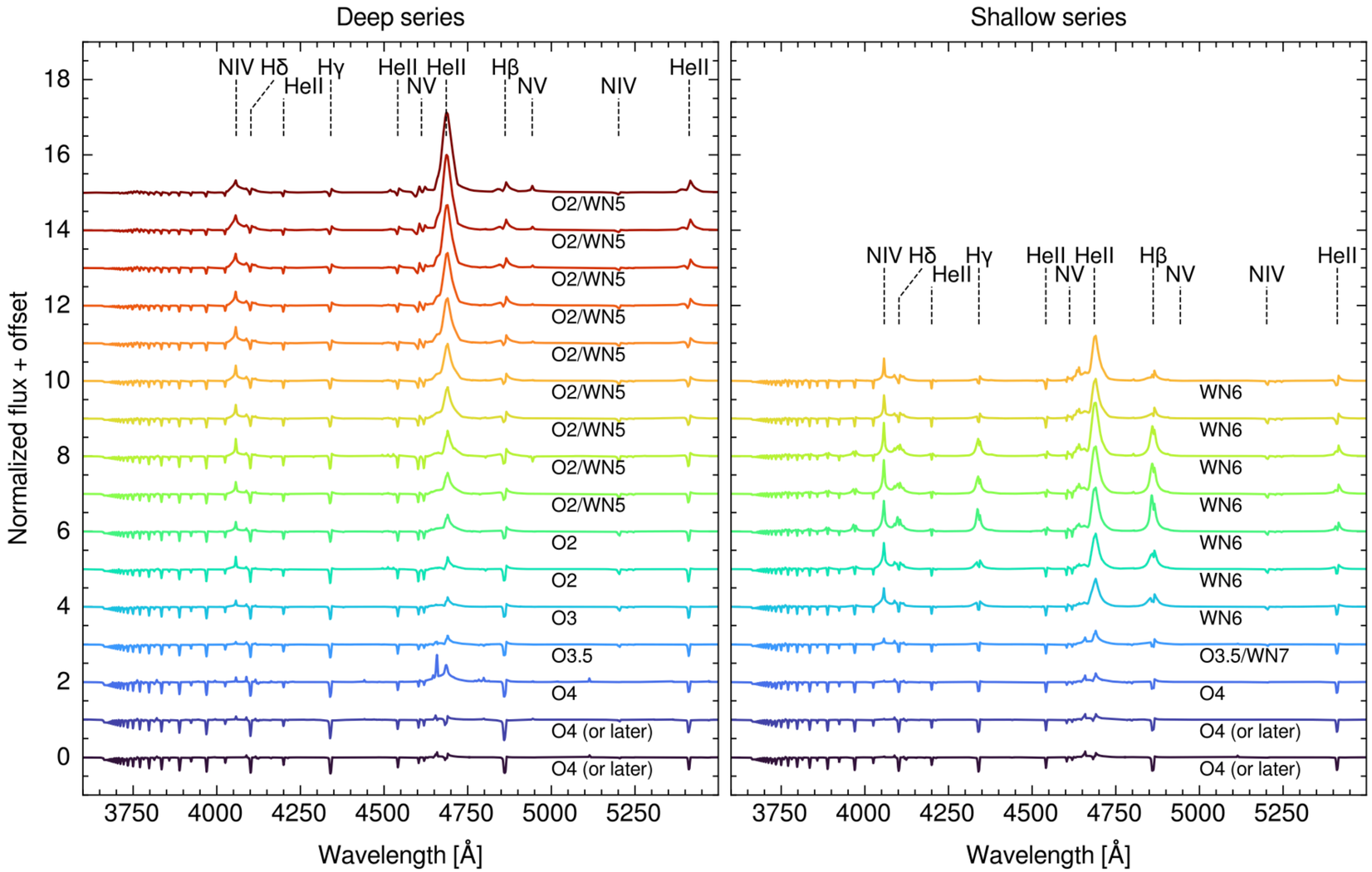



**“real” density structure requires implementing opacity-dependent turbulence in 1D.**

# spectral evolution



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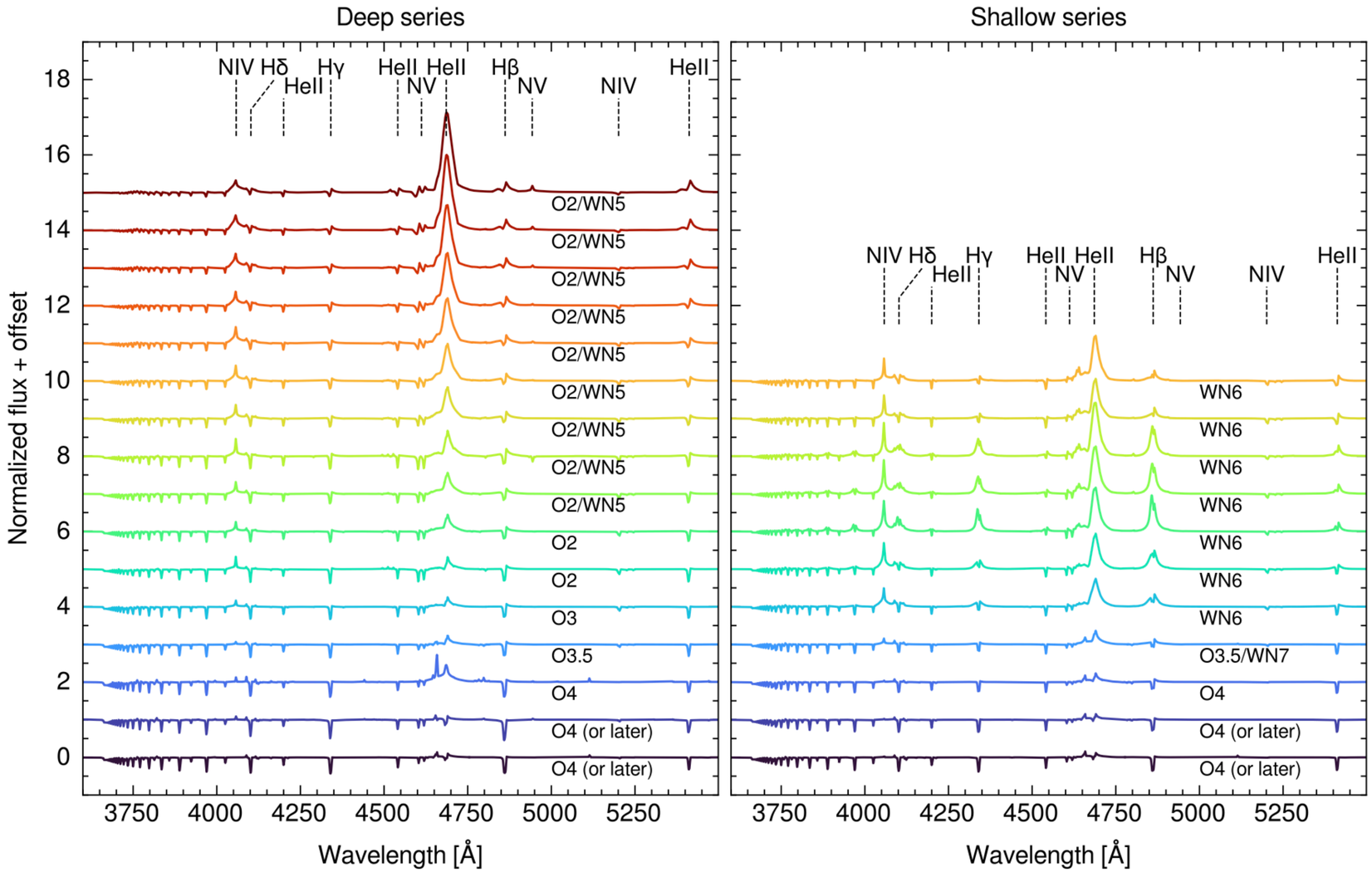


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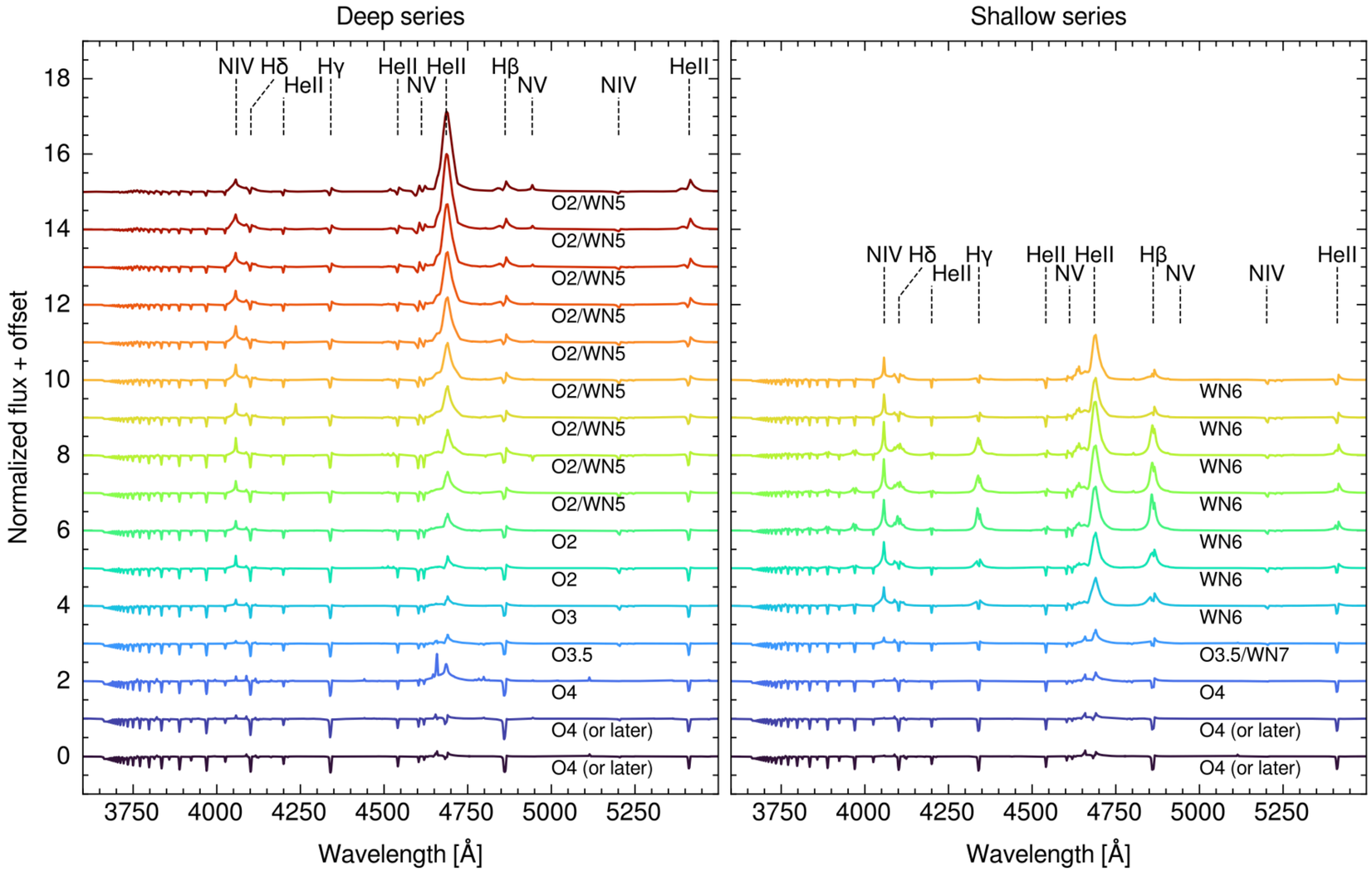


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**which spectra to trust??**

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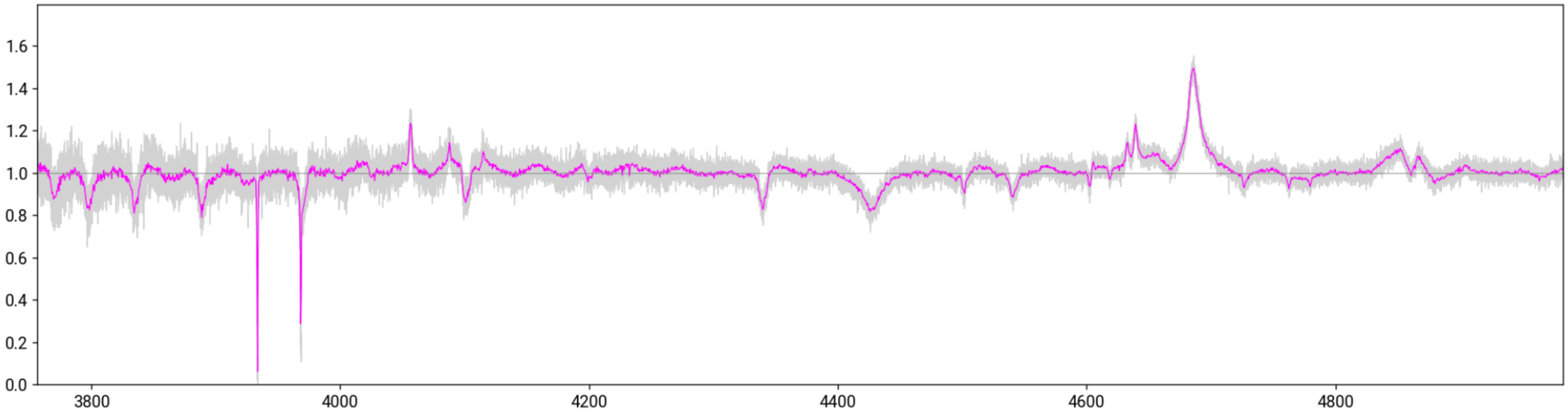

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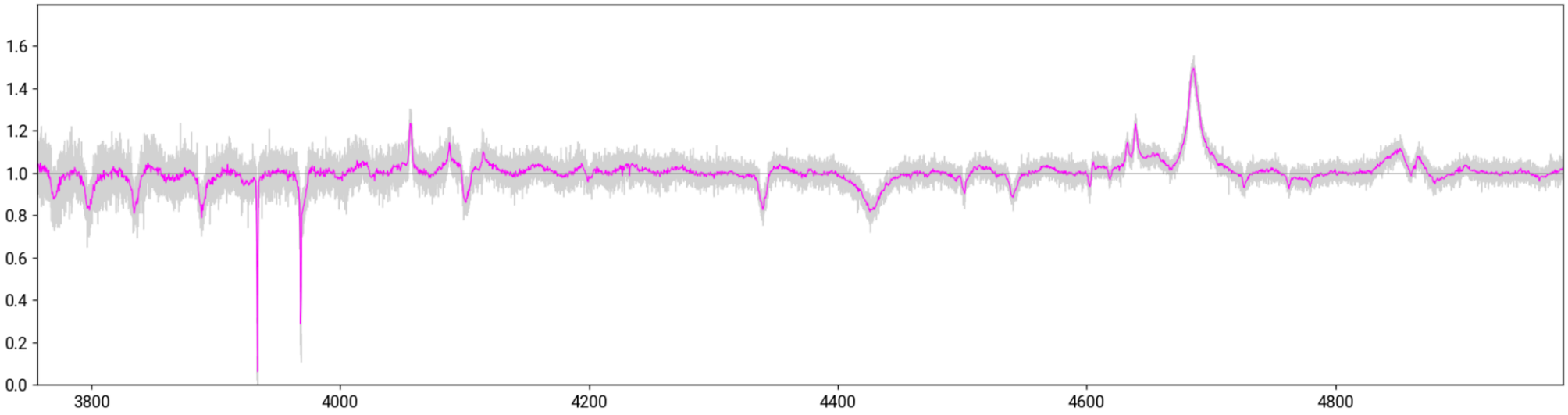


- backward evolution fitting (without $T_{\rm eff}$)